framework carrying these small vanes is attached to the front of the opening of the Marvin meteorograph. The vanes are calibrated by comparison with an anemometer, and must be recalibrated from time to time.

For use with his expansible India rubber sounding balloons, or Platz balloons, Assmann invented a very light meteorograph. To this end he adopted an endless roll of gelatinized Japanese silk paper. This endless roll passes over two small aluminum rollers, of which the upper one is moved step by step by the aneroids, which act on ratchets attached to either end of the upper roller, while a weight on the lower roller keeps the sheet stretched smooth. The thermometer is a metallic one, consisting of two circular plates of metal, copper and invar (Guillaume's nickelsteel), soldered together. The motion of the free end of this compound ring is magnified by levers, which eventually move a delicate silk thread running over a wheel so that its recording pen marks the temperature curve on the sheet of silk at right angles to the direction of its motion. This pen describes a nearly closed curve from the beginning to the end of any ascension, which curve is a function of the pressure and temperature. The thermograph and the hair hygrometer are inclosed in a vertical polished aluminum tube, which protects them from direct solar radiation. When the balloon falls to a pressure of about 600 millimeters, the pens are mechanically lifted and their record ceases. This arrangement has the advantage that we may thus clearly discriminate between the ascending and the descending curves; it also preserves the whole record from injury or other damage when the kite falls to the ground, especially if the instrument remains a long time in the open air and is tossed about by the winds. In order to know whether the balloon actually bursts or how long it floats at a high level, exposed to the sunshine, there is added a clock, which also makes a record on the same sheet. This new form of meteorograph is inclosed in a box of magnalium; it weighs 620 grams and can be furnished for 360 marks by R. Fuess, Steglitz.

In order to measure the angular altitude of a kite carrying a meteorograph a special apparatus was used; a Steinheil astronomical telescope with a large field of view and a pair of cross wires in the center was furnished with horizontal and altitude circles reading to 0.1°; a self-recording apparatus was contrived so that this really constituted a "goniograph." The observer has only to keep the cross wire pointed on the balloon or kite as closely as possible, and the apparent altitude and azimuth are simultaneously recorded on two sheets of paper from time to time. At the new observatory at Lindenberg it is proposed to keep two of these goniographs at work, at the ends of a short base line, in order to calculate the location of kite or balloon at any moment.

The work at Tegel is to be considered as preliminary to future work. Four hundred and seventy-five ascensions were made, of which 356 occurred during the fifteen months whose results are published in the present volume. They may be classified as follows:

(A) Fifteen ascensions of manned balloons; of these the longest voyage was 1470 kilometers in twenty-nine hours to the government of Poltava, in southern Russia, by Professor Berson and Doctor Elias; the highest ascent was 7832 meters.

(B) Twenty-two ascensions of free sounding balloons of the Assmann type, one of which was lost. The average altitude attained by 21 of these was 9816 meters. The average of the 17 highest was 11,157 meters, 3 rose above 19,000 and the maximum was 19,960 meters.

(C) Two hundred and five kite-balloon flights and (D) 103 kite flights. The excess in the number of flights of kite balloons was due largely to the fact that Doctor Elias was engaged in his study of the formation of fogs and also to the fact that at first there was no great familiarity with the management of kite ascents; but all this was changed in August, 1902, when Professor Assmann ventured to start with daily flights in any kind of weather, and the use of kite balloons was then reduced to a minimum. Under these conditions very often a kite ascent was accomplished when at first sight it seemed impossible on account of the feeble winds near the surface. In such cases by unrolling several hundred meters of wire, laying it out in the direction of the feeble wind, attaching the kite and reeling in with great speed, they produced an "artificial" wind, which increased the actual wind so that the kites were thrown up into a stratum of air of greater velocity. But very often the trees around the observatory prevented such experiments. In a similar way when much line had been played out and the kites, owing to the feeble upper wind, did not rise high, they were forced to rise higher by reeling in rapidly. Frequently when the kite was caught in the top branches of a tree it was necessary for an archer to shoot a light arrow carrying a light line over the tree; by this line a stronger one was drawn up and over, so that one could climb up to the kite and rescue it, or at other times the balloon was used to lift the kites from the trees.

As regards the personnel of the observatory it may be said to consist of the director, Professor Assmann, the permanent assistants, Professor Berson and Doctor Elias; and clerical work is done by Messrs. Dintner, Brehm, Koercke, and Koblenz.

The most expert mechanician, Thieme, was continually engaged in building and repairing the meteorological and other instruments, while R. Schmidt and W. Mund usually assisted during the kite flying, and F. Schmidt acted as balloon inspector. A carpenter was also continually employed, as mentioned above, in building and mending the kites.

The observatory at Tegel constituted a division of the Central Meteorological Office. But it is understood that the new establishment at Lindenberg will be an entirely separate institution for aerial research under Professor Assmann.

Appended to the record of kites and balloons is a paper on the formation of fogs by Doctor Elias that was translated in part by Mr. Proctor for the MONTHLY WEATHER REVIEW for September, 1904.

A second appendix by Berson and Elias gives the results of kite flying over the Baltic Sea, the North Sea, and Norwegian waters. These flights were made during their vacation excursion to Spitzbergen on the steamer *Oihonna*. On this occasion all the instruments and kites were supplied by the Tegel Observatory in order to practically test the well-known idea of Mr. Rotch as to the possibility of flying kites on the open sea from ships. Mr. Dines and Teisserenc de Bort had also done some work in this line following the idea of Mr. Rotch, and quite recently the Prince of Monaco has done so near the the Azores, according to the report of Professor Hergesell to the International Aeronautical Congress held last year, 1904, in St. Petersburg. On the Bodensee, in Switzerland, Hergesell and Zeppelin have also used a steamboat with success. Ascensions were made by Berson and Elias nearly every day from August 3 to 29 from the steamer *Oihonna*, and the results are given in full, showing in general that this method can be applied everywhere.

EVAPORATION OBSERVATIONS IN THE UNITED STATES.

By HERBERT HARVEY KIMBALL, Librarian, U. S. Weather Bureau.

[Read before the Twelfth National Irrigation Congress at El Paso, Tex., November 16-18, 1904.]

It is important that irrigation engineers should know not only the rainfall, but also the evaporation over any given region. Unfortunately, the measurement of evaporation presents many more difficulties than the measurement of precipitation. In fact, the rate of evaporation from land surfaces depends upon so many different elements that it can be treated only in the most general manner. Thus, it has been shown that the evaporation from saturated soil covered with growing plants is greater than from a water surface, but becomes less when the level of complete saturation falls a few inches below the soil surface, and continually diminishes as this level recedes to increasing depths. Also, the evaporation from a forest of evergreen trees is greater than from a forest of leafy trees; from the latter it is greater than from grass, from which in turn it is greater than from bare soil. The composition of the soil has its effect upon the rate of evaporation, and so also has the state of cultivation. Furthermore, the rate of evaporation from any surface has been found to vary with its temperature, with the quantity of moisture in the air, and with the wind velocity.

Even if we were able to determine the exact relation between each of these elements and evaporation, we see at once how hopeless it would be to undertake to compute accurately the evaporation over any very extended region of land surface. It is therefore customary to deduct the run-off from the rainfall over a watershed, and to attribute the difference to evaporation. This has been done by Mr. George W. Rafter in "Water Supply and Irrigation Papers No. 80, U. S. Geological Survey," for twelve drainage basins in the eastern part of the United States, as follows:

Drainage basins.	Years of record.	Rainfall.	Run-off.	Evaporation.
		Feet.	*Feet.*	*Feet.*
1. Muskingum River, Ohio	1888–1895	39.7	13.1	26.6
2. Genesee River, N. Y	1890–1898	40.3	14.2	26.1
3. Croton River, N. Y	1877–1899	49.4	22.8	26.6
4. Lake Cochituate, Mass	1863–1900	47.1	20.3	26.8
5. Sunbury River, Mass	1875–1900	46.1	22.6	23.5
6. Mystic Lake, Mass	1878–1895	44.1	20.0	24.1
7. Neshaminy Creek, Pa	1884–1899	47.6	23.1	24.5
8. Perkiomen Creek, Pa	1884–1899	48.0	23.6	24.4
9. Tohickon Creek, Pa	1884–1898	50.1	28.4	21.7
10. Hudson River, N. Y	1888–1901	44.2	23.3	20.9
11. Pequannock River, Conn	1891–1899	46.8	26.8	20.0
12. Connecticut River, Conn.	1872–1885	43.0	22.0	21.0

The rainfall and run-off have been computed for many other watersheds in the United States, particularly in California, where the run-off is a much smaller percentage of the rainfall than in the Eastern States.

As a practical problem in irrigation, however, the evaporation from water surfaces is of much more importance than the evaporation from land surfaces. The engineer will naturally determine his water supply, not from the annual precipitation, but from the run-off of available streams. Having ascertained this, the question of losses becomes important, and if storage basins are of considerable area the loss by evaporation in a dry climate becomes very serious, having been estimated, in some cases, to be as much as 30 to 50 per cent of the amount stored.

Fortunately, the determination of the evaporation from a water surface presents fewer difficulties than the evaporation from land surfaces. Generally speaking, the determination may be made by two quite different methods; (1) by direct measurements from properly exposed water surfaces, and (2) by computations based upon the temperature of the water surface and the value of certain meteorological elements. With proper attention to exposure, direct measurements of evaporation from water surfaces should give the more reliable results. Unfortunately, proper exposure is not always practicable, and it is therefore necessary to consider the character of the exposure in connection with each series of evaporation experiments, and in some cases to apply a correction before the results will fairly represent the evaporation from a reservoir or a lake.

One of the most exhaustive series of evaporation experiments in the United States was conducted by Mr. Desmond Fitzgerald,[1] between the years 1876 and 1886, in connection with the reservoirs of the Boston waterworks. He not only measured the evaporation directly by means of tanks floating on the surface of reservoirs, some of them arranged to record automatically the rate of evaporation, but he also conducted elaborate experiments to determine the relation between the rate of evaporation and the temperature of the water surface, the temperature of the air, the amount of moisture in the air, and the movement of the air.

He found that the rate of evaporation depended upon three elements; the vapor pressure corresponding to the temperature of the surface of the water, the vapor pressure corresponding to the dew-point of the atmosphere, and the velocity of the wind.

Representing by E the evaporation in inches per hour from a water surface, by e_s the vapor pressure in inches corresponding to the surface temperature of the water, by e_d the vapor pressure corresponding to the dew-point of the atmosphere, and by v the wind velocity in miles per hour, he obtained:

$$E = 0.0166\ (e_s - e_d) \left(1 + \frac{v}{2}\right)$$

as the equation for the hourly rate of evaporation. This equation he found to hold good for an ice surface as well as for a water surface, in the shade as well as in the sunshine, and by night as well as by day.

Measurements of evaporation from the water in a tank three feet cube, the top flush with the surface of the ground, have been made since 1887 at Fort Collins, Colo.,[2] under the direction of Prof. L. G. Carpenter. The temperature of the water in the tank was found to be lower than the temperature of the water in reservoirs and lakes in the victnity, and in consequence the evaporation was less. Fitzgerald[3] notes a like deficiency in temperature and evaporation in connection with tanks set in the ground near Croton Reservoir, N. Y., but at Lakeport and Kingsbury Bridge, Cal., the temperature and the evaporation, as measured in a tank set in the ground, were found to exceed like measurements in tanks floating in lakes. Since a great many measurements of evaporation have been made from tanks set in the ground, it is important that these discrepancies in water temperature and evaporation be borne in mind.

From his investigations in 1889 Professor Carpenter found that the daily evaporation could be very accurately expressed by the equation:

$$E = 0.3868\ (e_s - e_d)\ (1 + 0.0025\ W),$$

where W represents the wind movement in twenty-four hours, the other symbols having the same significance as in Fitzgerald's equation. Reduced to a like period (twenty-four hours), the latter becomes:

$$E = 0.3984\ (e_s - e_d)\ (1 + 0.0208\ W).$$

The agreement between the two is quite remarkable when we consider the difference in the climatic conditions at the two stations. The difference in the values of the coefficient of W was attributed by Professor Carpenter to the fact that Fitzgerald measured the wind velocity at the surface of the water, while Carpenter's wind velocities were obtained from an anemometer on the roof of the college building.

Subsequent observations served to confirm the accuracy of Carpenter's formula, and after ten years, by means of comparative readings between his standard tank and tanks floated on water surfaces, he computed the average annual evaporation from a free water surface at Fort Collins to be 59.5 inches instead of 46.3 inches, as he had measured it.

In 1887 and 1888 Prof. T. Russell,[4] of the U. S. Signal Service, investigated the rate of evaporation in standard ther-

[1] Transactions of the American Society of Civil Engineers, vol 15, p. 581.

[2] See Annual Reports of the Agricultural Experiment Station, Fort Collins, Colo.

[3] Proceedings of the American Society of Civil Engineers, vol. 15, p. 617.

[4] Monthly Weather Review, 1888, p. 235.

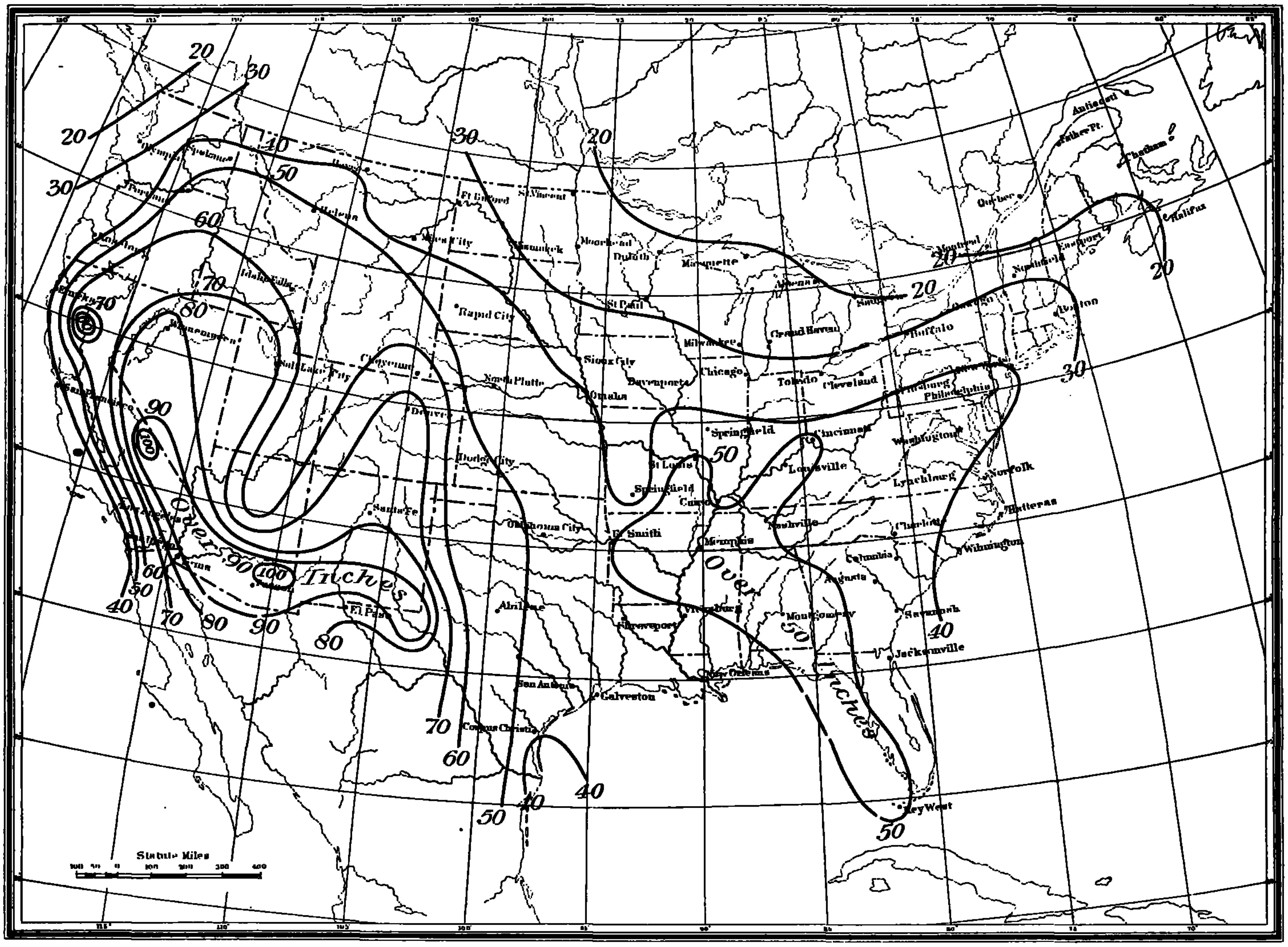

FIG. 1.—Lines of equal annual depth of evaporation in inches from a free water surface, computed from meteorological observations from July, 1887, to June, 1888.

mometer shelters, by means of observations with Piche evaporimeters. This instrument, as is well known, consists of a glass tube about nine inches long and 0.4 inch internal diameter, hermetically sealed at the top. Over the bottom is placed a disk of porous paper, which is held in position by a copper disk pressed against the open end of the tube by a suitable spring attachment. Capillary action keeps the paper moist. Its exposed area is known, and the amount of evaporation is determined by means of a scale etched on the side of the tube.

To determine the relation between the rate of evaporation from a Piche evaporimeter and a water surface Professor Russell exposed two of the Piche instruments in a closed room in which were two open tin dishes filled with water. Both the Piche evaporimeters and the dishes were weighed at frequent intervals, and it was found that the Piche instruments evaporated 1.33 times as fast as the open dishes. Eighteen Piche instruments were then exposed at various Signal Service stations, from May 31 to September 30, 1888, and the observed quanity of evaporation was divided by 1.33 to reduce it to the evaporation from a water surface. By the method of least squares, the relation between the rate of evaporation, the temperature of the evaporating surface, and the amount of moisture in the air was determined from observations made during the month of June. The temperature of the evaporating surface in this case was the same as that of the wet-bulb thermometer. The monthly rate of evaporation was found to be quite accurately expressed by the equation:

$$E=30\left[\frac{43.88\,(e_w-e_d)\,+1.96\,e_w}{B}\right]$$

in which e_w is the vapor pressure in inches corresponding to the monthly mean temperature of the wet-bulb thermometer, e_d is the vapor pressure corresponding to the monthly mean dew-point of the atmosphere, and B the monthly mean barometric pressure in inches. By means of this formula Professor Russell computed the monthly evaporation at 140 Signal Service stations from July, 1887, to June, 1888, inclusive, using the monthly mean wet-bulb and dew-point temperatures derived from tridaily observations. From the data thus computed, the accompanying chart showing "Lines of equal annual depth of evaporation in inches from a free water surface" was prepared. Professor Russell states his belief that this chart represents approximately the evaporation that takes place from the surfaces of ponds, rivers, reservoirs, and lakes in the vicinity of Signal Service stations, basing his belief principally upon the results of evaporation experiments conducted under the direction of the Central Physical Observatory at St. Petersburg, from May to October, 1875, and discussed by Ed. Stelling in Band VIII, No. 3, of Wild's Repertorium für Meteorologie, 1882. Stelling's equation, however, is:

$$E=A\,(e_s-e_d)\,(1-Bv)$$

which is identical in form with Fitzgerald's, the symbols having the same significance. His constants, E, A, and B, which are computed for the centigrade system, were found to vary with the seasons, and are therefore not easily comparable with Fitzgerald's.

Russell's formula, however, departs radically from those of Fitzgerald, Carpenter, and Stelling, in that it substitutes the vapor pressure corresponding to the temperature of the wet-bulb thermometer for the vapor pressure corresponding to the temperature of the surface of the water, and adds a term depending upon this same vapor pressure, e_w, in place of the wind velocity term. This latter is dropped, and the equation represents the evaporation with a wind velocity outside the shelter of 7.1 miles per hour, which was the average at the stations where the Piche observations were being made, during June, 1887.

It is evident that this wind velocity will not apply to all parts of the United States for all seasons of the year. Neither will it do to substitute the temperature of the wet-bulb thermometer for the temperature of the water surface, the former being cooler than the latter. No doubt the additive term containing e_w compensates for this in a measure, but we must conclude that Russell's formula does not rest upon as sound a physical basis as do the formulas of Stelling, Fitzgerald, and Carpenter. The term $\frac{1}{B}$ was introduced on account of the wide variations in the value of B at the different stations. It is unimportant when discussing the observations at a single station.

Upon the organization of the Irrigation Survey by the U. S. Geological Survey in 1888, arrangements were made for measuring the evaporation at several points in the arid regions of the United States. It was recognized that the rate of evaporation depended upon the dryness of the air, the temperature of the water surface, and the velocity of the wind at the water surface. An effort was therefore made to measure the evaporation from a water surface having the same temperature as the surface of lakes or reservoirs, and exposed to the same wind velocity. To accomplish this galvanized-iron evaporating pans, three feet square and eighteen inches deep, were floated on the surface of the body of water from which the evaporation was to be measured. The pans were kept nearly full, with the surface of the water in them about on a level with the water outside. The evaporation was at first measured by some sort of gage, but later was determined from the amount of water that was added to bring the surface to the top of a pin projecting from the center of the pan. A record of the water temperature inside and outside the pans was kept. Usually a difference was noted, the inside temperature being higher in the daytime and lower at night. The average is, however, about the same in each. It is not probable that the water in pans is exposed to quite so high a wind velocity as the average over outside surfaces, but to offset this the water in the pan wets the sides, and this increases the evaporating surface. It is therefore assumed that in general the evaporation from a floating pan of this type when kept nearly full represents the evaporation from the outside water surface very closely.

Several of the agricultural experiment stations measure the evaporation from pans, but most of the pans are set in the ground, and for reasons already given their indications are not believed to represent the evaporation from reservoirs and lakes as closely as do those from floating pans.

For the purpose of checking Russell's computed values, the following table has been prepared. In the first two columns are the names of stations and the evaporation computed by Russell. In the following columns are the names of neighboring stations at which measurements of evaporation from water surfaces have been made, the amount of evaporation measured, and the character of the exposure. We are thus enabled to judge of the probable value of Russell's chart.

Annual evaporation.

Russell's formula.		Surface measurements.		
Stations.	Evaporation.	Stations.	Evaporation.	Exposure.
	Inches.		*Inches.*	
Boston, Mass.	34.4	Boston, Mass.	34.78	Beacon Hill Reservoir.
New York, N. Y	40.6	Boston, Mass.	39.11	Chestnut Hill Reservoir, floating pan.
Cheyenne, Wyo.	76.5	New York, N. Y	39.64	Croton Reservoir, floating pan
		Laramie, Wyo	46.30	Ground.
		Fort Collins, Colo.	46.16	Ground.
El Paso, Tex.	82.0	Fort Collins, Colo.	59.50	Computed for reservoir.
		Fort Bliss, Tex.	82.65	Floating pan.
Salt Lake City, Utah.	74.4	Fort Douglas, Utah	42.46	Floating pan.
Fort Grant, Ariz.	101.2	Tucson, Ariz.	75.78	
Prescott, Ariz.	56.0	Tempe, Ariz.	65.00	Floating pan.
Sacramento, Cal	54.3	Clear Lake, Cal	32.38	Floating pan.
		Clear Lake, Cal	33.40	Ground.
Fresno, Cal	65.8	Kingsbury Bridge, Cal.	47.79	Floating pan.
		Kingsbury Bridge, Cal.	59.49	Ground.
Los Angeles, Cal	37.2	Arrowhead Reservoir	36.60	Ground. (Elev. 5,160 ft.)
San Diego, Cal	37.5	Sweetwater Reservoir	57.55	Floating pan.

The results above given are not strictly comparable, since the stations are not in all cases identical, and in some cases, especially in California, the reservoirs are at a greater height than the Weather Bureau stations, and in consequence the water surfaces are correspondingly colder. Generally speaking, Russell's results appear to be the higher.

Since Russell's equation was deduced from tridaily observations, it is not applicable to the present 8 a. m. and 8 p. m. observations of the Weather Bureau unless one first applies a correction to the mean of these two observations to reduce it to the mean derived from tridaily observations. The equations of Fitzgerald and Carpenter appear to have a quite general application, provided we know the temperature of the water surface, the dew-point, and the wind velocity. It would seem, therefore, that in the absence of reliable measurements of evaporation from water surfaces, an effort should be made to determine the temperature of water surfaces near Weather Bureau stations, and where the evaporation is measured from tanks sunk in the ground the relation between the temperature of this evaporation surface and the temperature of lakes or reservoirs in the vicinity should be carefully determined.

Seasonal evaporation naturally varies with geographical position. Some of its peculiarities are shown in the following table:

Evaporation in inches.

Month.	Boston, Mass.	Fort Collins, Colo.	Clear Lake, Cal.	Fort Bliss, Tex.
January	0.90	1.50	0.85	2.35
February	1.20	2.00	0.60	2.45
March	1.80	3.50	2.00	6.25
April	3.10	5.00	2.82	7.35
May	4.61	6.50	3.85	10.85
June	5.86	8.00	4.30	11.20
July	6.28	9.50	5.90	9.60
August	5.49	8.50	4.70	9.50
September	4.09	6.50	3.72	9.20
October	2.95	4.50	2.12	6.80
November	1.63	2.50	0.65	4.15
December	1.20	1.50	0.85	2.95
Year	39.11	59.50	32.38	82.65

Several series of evaporation measurements that do not cover the winter season have not been referred to in this paper. While they are of value, the above table indicates the importance to irrigation engineers of making the readings throughout the entire year.

PERPENDICULAR COLD AIR MOVEMENTS AS RELATED TO CLOUD VELOCITY.

By WILLIAM ABNER EDDY, Bayonne, N. J. Dated January 9, 1905.

While flying kites at Stamford, Delaware County, N. Y., in the Catskill Mountains, during a cloudy day threatening rain,